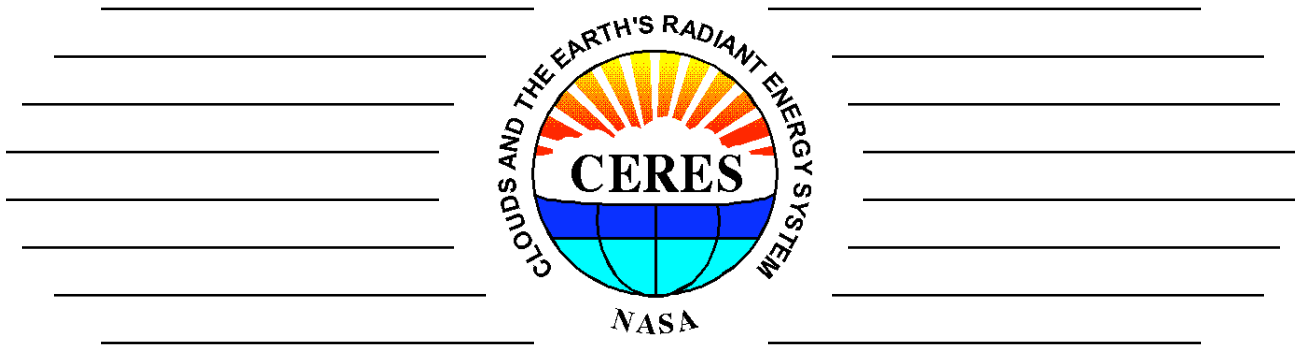
CERES Instrument Radiometric Performance



Kory J. Priestley
Susan Thomas, Denise Cooper, Dale Walikainen,
Phil Hess, Grant Matthews, Peter Szewczyk, Robert Wilson

CERES Science Team
Hadley Center
Exeter, UK
October 25, 2006

Presentation Structure

- **Part 1 - Priestley**
- Project status, NGST contract - hardware procurement
- Review performance status
- Present Calibration Plan / Philosophy
- Introduce the concept of contaminant and SW spectral degradation
- Ground based studies to quantify
- On-orbit operations to isolate, quantify

- **Part 2 - Matthews**
- Review Edition3_beta test runs
- Identify changes incorporated
- Present results
- Identify Edition3 changes for production


INSTRUMENT WORKING GROUP
CLOUDS AND THE EARTH'S RADIANT ENERGY SYSTEM
Introduction
Activities
Documentation
Operations
Production
Data
Personnel
ACTIVITIES
Choose from one of the links below:
Ground Calibration
Deep Space Calibration
Validation
Field Campaigns:
CLAMS
CRYSTAL-FACE
INDOEX
LaRC-ULDB
GERB
Aerosols
Terra/Aqua Intercalibration
Solar Principal Plane Scans (PPS)
Event Calendar:
2003
http://asd-www.larc.nasa.gov/Instrument/
NASA LaRC
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Last Updated: Tue Apr 29 13:03:55 2003
Web Curator: Phil Hess (p.c.hess@larc.nasa.gov)
Responsible NASA Official: Kory Priestley (k.j.priestley@larc.nasa.gov)
CERES Home Page

CERES Project Status

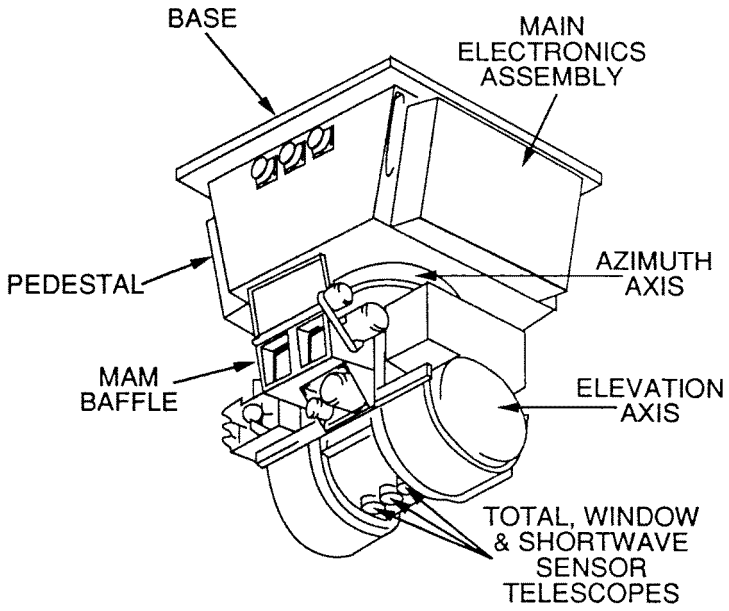
Current contract with instrument provider (NGST) concludes on 12/31/06

- **Ongoing effort to optimize the remaining schedule and $$.**
- **Final work package(I.e. contract modification) consists of…**
  - **Functional Recalibration of FM-5 (completed 10/10/06)**
  - **Contamination study of spare optical components**
  - **Preliminary investigation of MAM stability improvements**
  - **Repeating key component spectral reflectance measurements**

- **What to do with FM-5 once contract ends? Options include…**
  - **Establish an additional procurement mechanism**
  - **Hand off to FM-5 to NPOESS IPO**
  - **Ship FM-5 to LaRC for storage and functional testing**

CERES Instrument

- Design is based upon the Earth Radiation Budget Experiment (ERBE) philosophy
- Instrument was designed, manufactured and tested by TRW (Redondo Beach, CA)
- Contains three sensor assemblies with cassegrain optics and thermistor bolometer detectors
- Sensors measure thermal radiation in the near-visible through far-infrared spectral region
- Three sensor channels are coaligned and mounted on a spindle which rotates about the elevation axis
- Hemispherical sampling obtained with an azimuthal axis drive system
- Calibration Accuracy Requirements - 0.5% LW, 1.0% SW



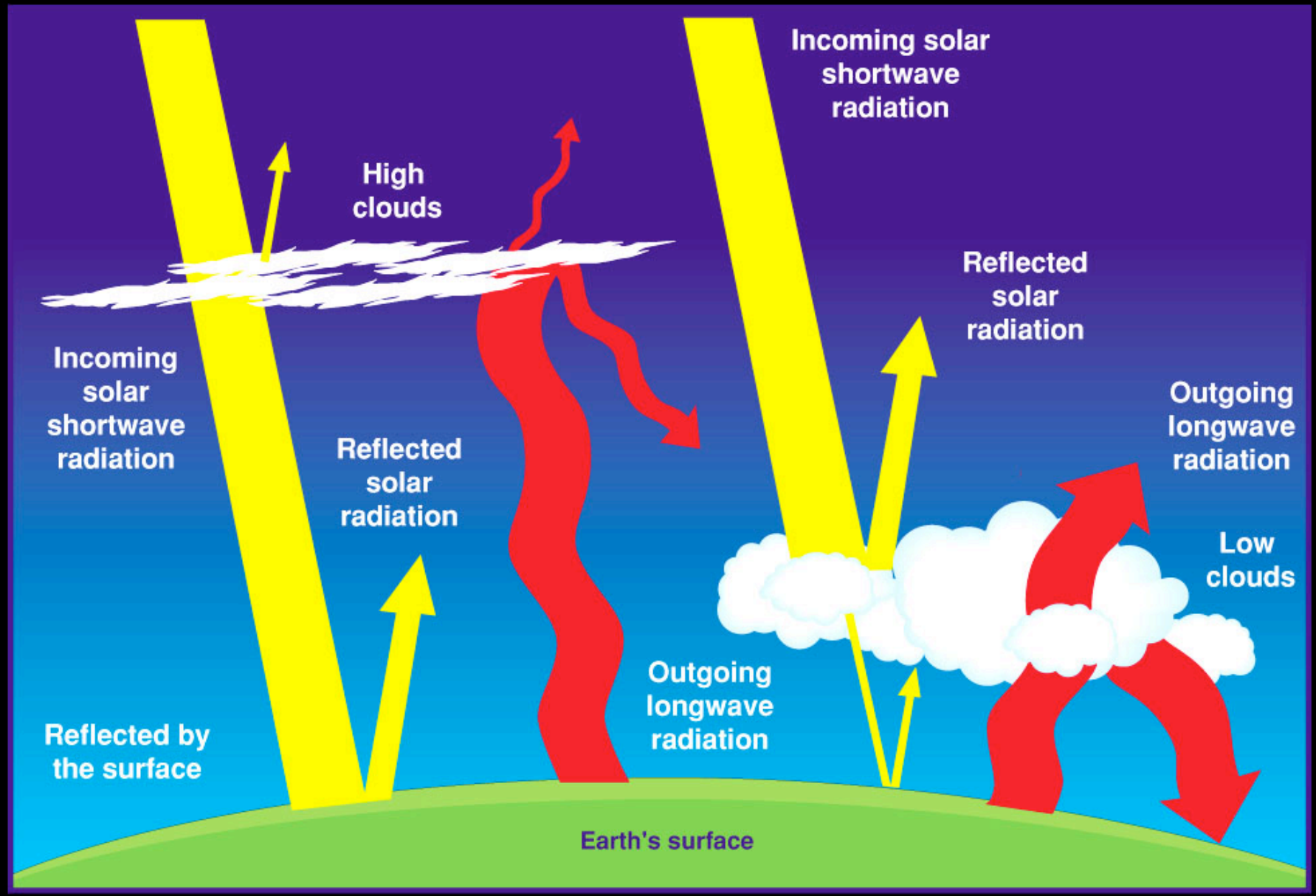
CERES Terra/Aqua Health & Status

With the exception of the SW channel on the CERES/Aqua FM-4 Instrument, the CERES Terra/Aqua instruments are functioning nominally…

Spacecraft	Instruments	Launch	Science Initiation	Collected Data (Months)
TRMM	PFM	11/97	1/98	9
Terra	FM1, FM2	12/99	3/00	78 +
Aqua	FM3, FM4	5/02	6/02	51 +
NPOESS C1	FM5	2013	?	?

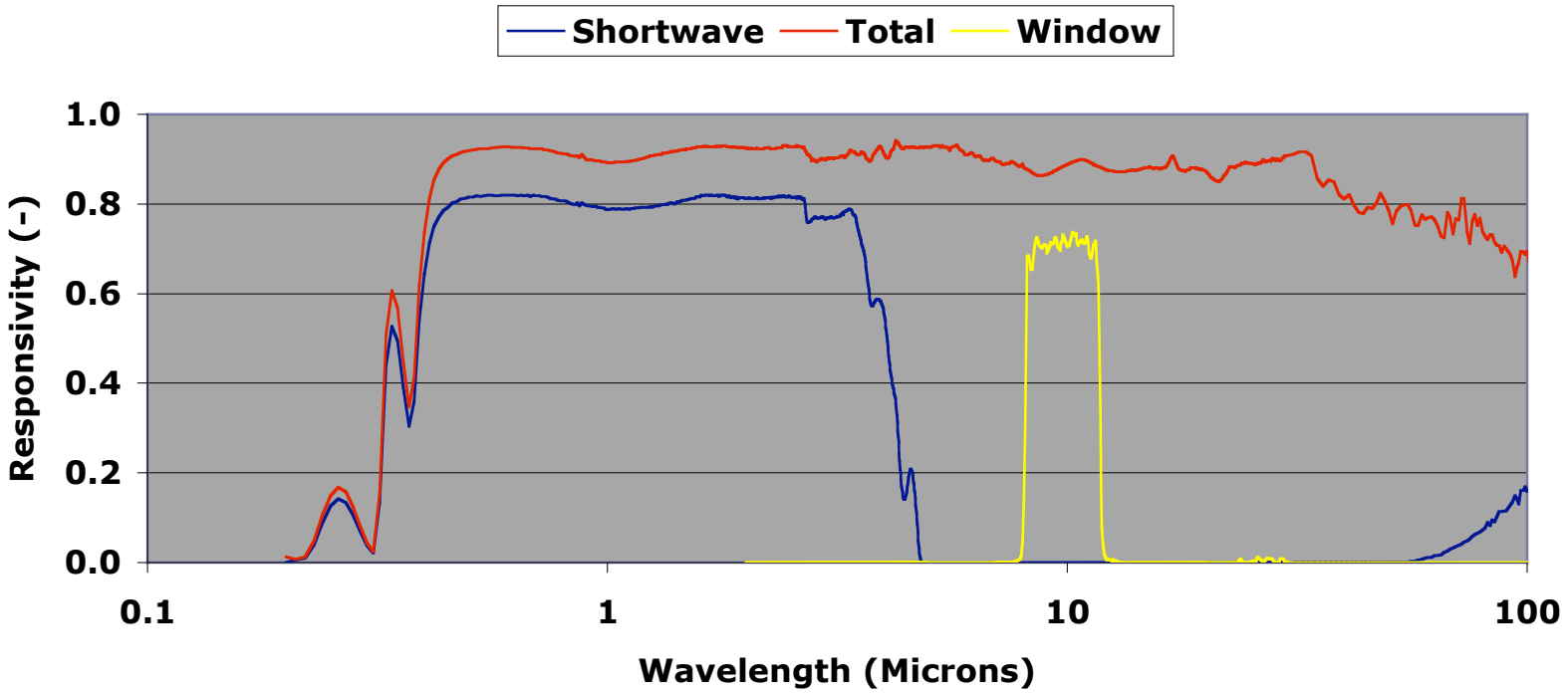
21.5 Instrument Years of Data

Cloud Effects On Earth's Radiation



CERES Spectral Response Function

TRMM/PFM Edition2 Data Products



Note: LW_{DAY} = Total - Shortwave

Radiometric Performance Requirements

5-Year CERES Mission Lifetime

Spectral Regions	Solar		Terrestrial		Atmospheric Window
Wavelengths	0.3 - 5.0 μm		5.0 - 200 μm		8 - 12 μm
Scene levels	<100 w/m^2-sr	>100 w/m^2-sr	<100 w/m^2-sr	>100 w/m^2-sr	All Levels
Accuracy Requirements	0.8 w/m^2-sr	1.0 %	0.8 w/m^2-sr	0.5 %	0.3 w/m^2-sr
Stability Requirements		< 0.14%/yr		< 0.1%/yr	
Climate Stability Goals		< 0.6 w/m^2/dec < 0.06 %/yr		< 0.2 w/m^2/dec < 0.02%/yr	

- **Requirements for CERES are more stringent than ERBE's by a factor of 2**
- **Requirements per Ohring et. al. are more stringent than CERES by a factor of 2-3**

Terra ES-8 Data Product Stability Summary

•**Cal/Val Protocol demonstrates radiometric stability of the data products through 12/2005 of….**

	Edition1		Edition2		Edition2_Rev1		Edition3_Beta	
	FM1	FM2	FM1	FM2	FM1	FM2	FM1	FM2
LWday	.3	.6	.125	.125	.125	.125	<.1	<.1
LWnight	.1	.125	<.1	<.1	<.1	<.1	<.1	<.1
SW	.2	.4	.2	.3	.1	.1	<.1	<.1
WN	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1

Note: Values apply to all-sky global averages
Units are in %/yr

Terra ES-8 Data Product Stability Summary

•**Cal/Val Protocol demonstrates radiometric stability of the data products through 12/2005 of….**

	Edition1		Edition2		Edition2_Rev1		Edition3_Beta	
	FM1	FM2	FM1	FM2	FM1	FM2	FM1	FM2
LWday	.3	.6	.125	.125	.125	.125	<.1	<.1
LWnight	.1	.125	<.1	<.1	<.1	<.1	<.1	<.1
SW	.2	.4	.2	.3	.1	.1	<.1	<.1
WN	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1

Note: Values apply to all-sky global averages
Units are in %/yr

Cal-Val Approach / Philosophy

Pre-Launch

- Implement a rigorous & thorough ground calibration/characterization program
- Cal/Val role must be prominent in original proposal and SOW
- System level characterization is typically last test performed prior to delivery of the instrument
- Cost and schedule constraints typically drive programs at that point

Post-Launch

- Implement a protocol of independent studies to characterize on-orbit performance
- Studies should cover all spectral, spatial and temporal scales as well as data product levels
- Continuous development of new validation studies
- Retain capability to perform ground based characterizations of flight components (Improved measurement techniques, support anomaly analyses)

Data Product Release Strategy

- Develop a logical and well understand approach to data release.
- Minimized the number of Editions/Versions of Data
- Utilize Data Quality Summaries for the community

On-orbit Cal-Val Sequence

The CERES instrument spectral bands do not correspond directly to data product spectral bands. For example…

$$LW_{day} = Total - Short$$

Therefore we need a logical approach to producing radiometrically accurate and stable data products.

In general we approach this in the following order of priority:

1. **SW Channel**
2. **Nighttime LW (i.e. Total channel at night)**
3. **Atmospheric WN Channel**
4. **Daytime LW**

BDS and ERBE-Like Release Strategy

Edition1_CV - Static Algorithms and coefficients - baseline product used in cal/val protocol, *should not be used for scientific studies*.

Edition2 - Utilizes temporally varying coefficients to correct for traceable radiometric drift. All spectral changes are broadband and 'gray'.

Edition3 - *Release date Early 2007*. Will incorporate temporally varying spectral artifacts in the SW measurements. A complete re-analysis of Ground Calibration with additional component characterization measurements.

User Applied Revisions - Advance capabilities to the users prior to the release of the next Edition.

Edition2 products lag Edition1 by a minimum of 4 months

Notification of Revision

ATMOSPHERIC SCIENCES DATA CENTER

CERES BDS (BiDirectional Scan) Terra Edition2 Data Quality Summary

Investigation: **CERES**
Data Product: **Bi**Directional **S**can [BDS]
Data Set: **Terra (Instruments: FM1, FM2)**
Data Set Version: **Edition2**

The purpose of this document is to inform users of the accuracy of this data product as determined by the CERES Team. This document briefly summarizes key validation results, provides cautions where users might easily misinterpret the data, provides links to further information about the data product, algorithms, and accuracy, gives information about planned data improvements. This document also automates registration in order to keep users informed of new validation results, cautions, or improved data sets as they become available.

This document is a high-level summary and represents the minimum information needed by scientific users of this data product. It is strongly suggested that authors, researchers, and reviewers of research papers re-check this document for the latest status before publication of any scientific papers using this data product.

Table of Contents

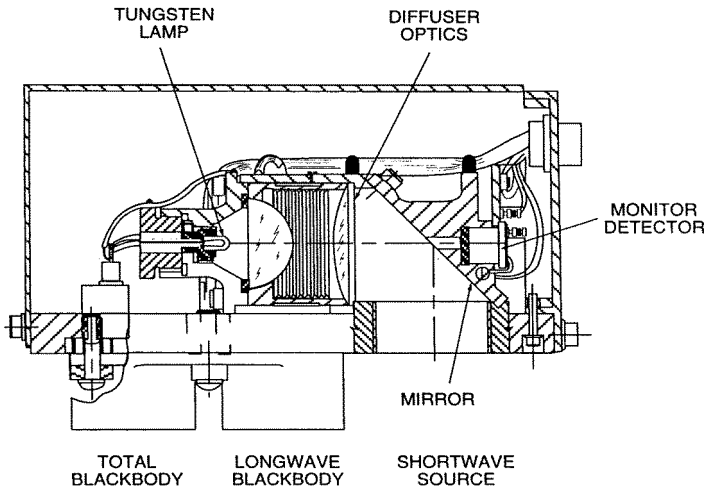
CERES Instrument Radiometric Validation Activities

		Product	Spatial Scale	Temporal Scale	Metric	Spectral Band
On-Board	Internal BB	Filtered Radiance	N/A	N/A	Absolute Stability	TOT, WN
	Internal Lamp	Filtered Radiance	N/A	N/A	Absolute Stability	SW
	Solar	Filtered Radiance	N/A	N/A	Relative Stability	TOT, SW
Vicarious	Theoretical Line-by-Line	Filtered Radiance	> 20 Km	Instantaneous	Inter-Channel Theoretical Agreement	TOT, WN
	Unfiltering Algorithm Theoretical Validation	N/A	N/A	N/A	N/A	TOT, SW, WN
	Inter-satellite (Direct Comparison)	Unfiltered Radiance	1-deg Grid	1 per crossing	Inter-Instrument Agreement, Stability	TOT, SW, WN
	Globally Matched Pixels (Direct Comparison)	Unfiltered Radiance	Pixel to Pixel	Daily	Inter-Instrument Agreement	TOT, SW, WN
	Tropical Mean (Geographical Average)	Unfiltered Radiance	20N – 20S	Monthly	Inter-Channel Agreement, Stability	TOT, WN
	DCC Albedo	Unfiltered Radiance	>40 Km	Monthly	Inter-Instrument agreement, Stability	SW
	DCC 3-channel	Unfiltered Radiance	>100 Km	Monthly	Inter-Channel consistency, stability	TOT, SW
	TIme Space Averaging	Fluxes	Global	Monthly	Inter-Instrument Agreement	LW, SW
	Lunar Radiance Measurements	Filtered Radiance	Sub Pixel	Quarterly	Inter-Instrument Agreement	LW, SW, WN

CERES Onboard SW Calibration Equipment

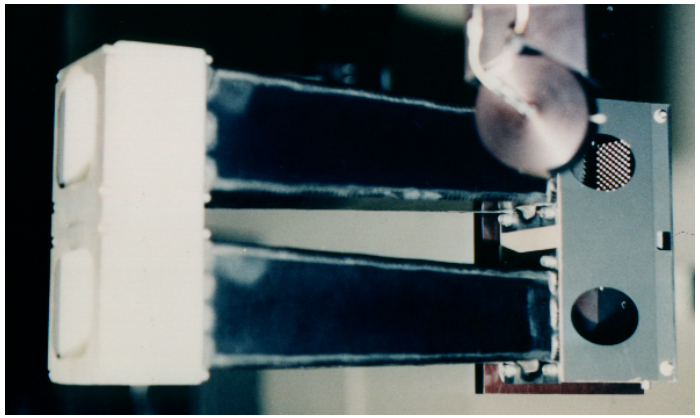
Shortwave Internal Calibration Source (SWICS)

- Quartz-halogen tungsten lamp (2100, 1900, 1700 K spectrums)
- SiPd independently monitors lamp output
- Design specification is +-0.5% stability over 5-year mission
- Designed primarily to transfer Ground Calibration measurements into orbit

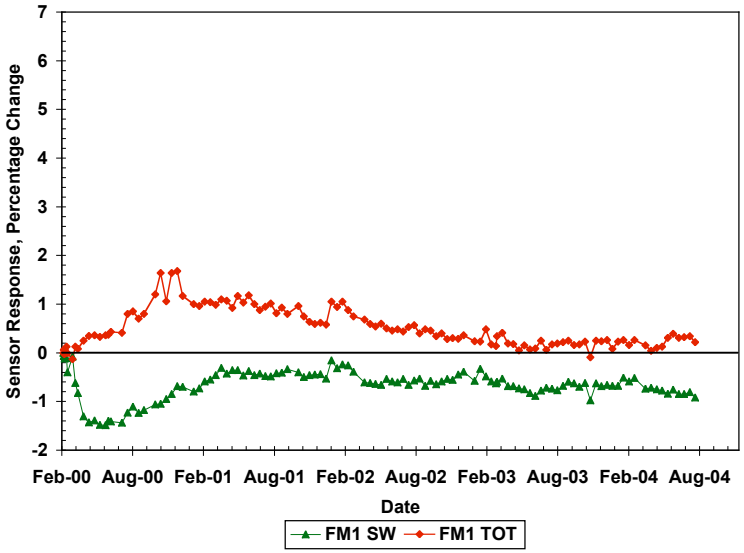


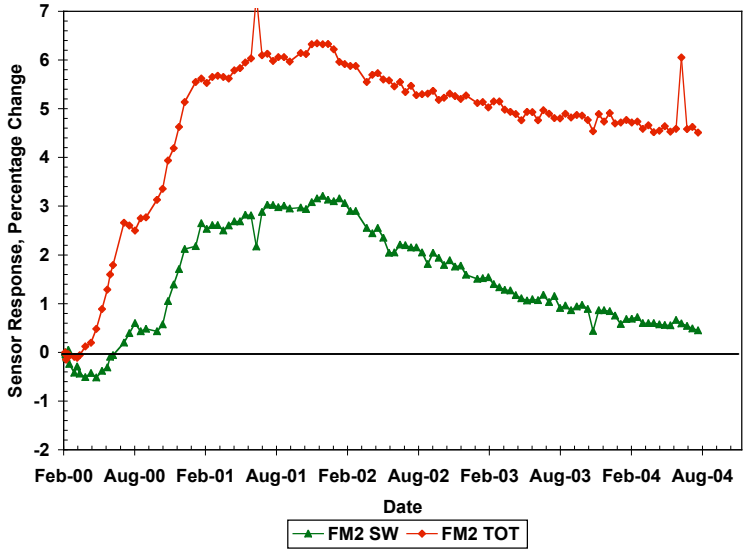
Mirror Attenuator Mosaic (MAM)

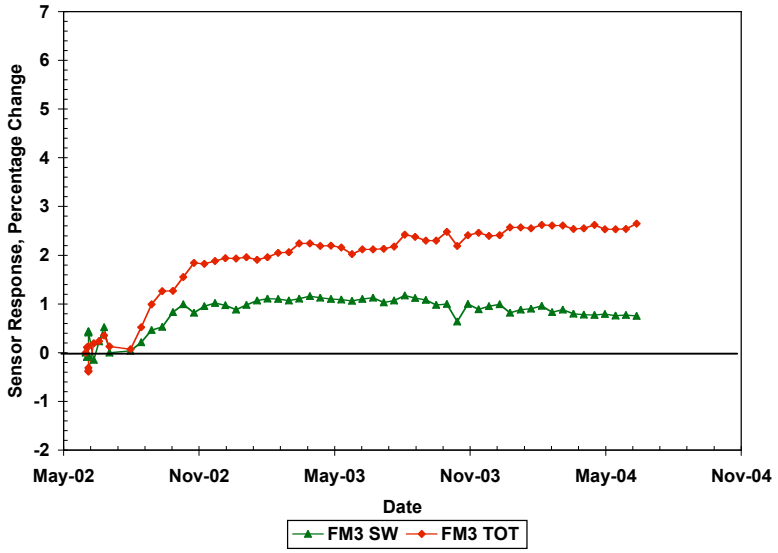
- Solar Diffuser plate attenuates direct solar view (~5800K Spectrum)
- MAM is a Nickel substrate with Aluminum coated spherical cavities or divots
- Provides a Relative calibration of the Shortwave channel and the SW portion of the Total channel
- Designed to provide a long-term on-orbit SW calibration source.
- Solar Cal results to date are suspect due to large initial drift in MAM surface reflectances…

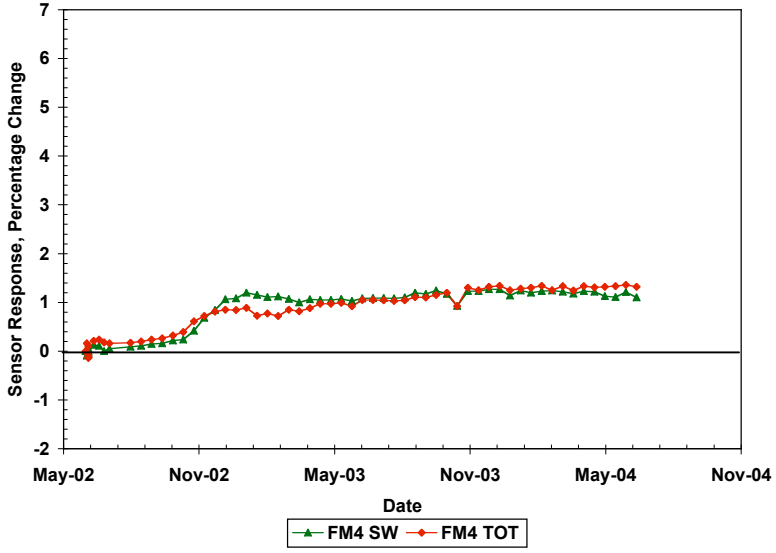


CERES Solar Calibration Results

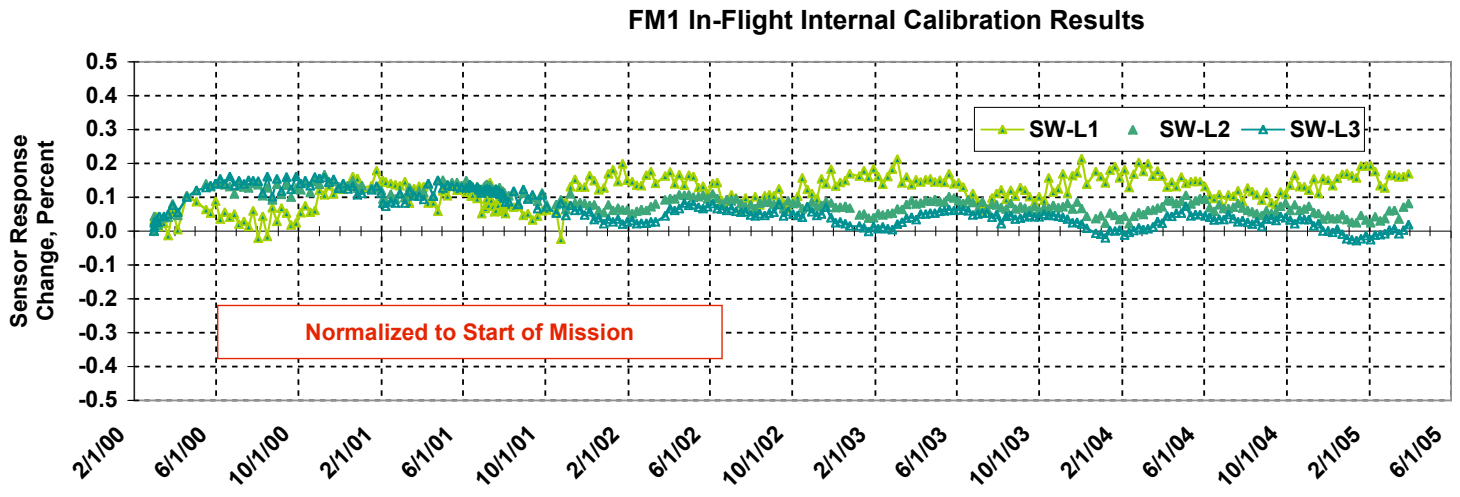


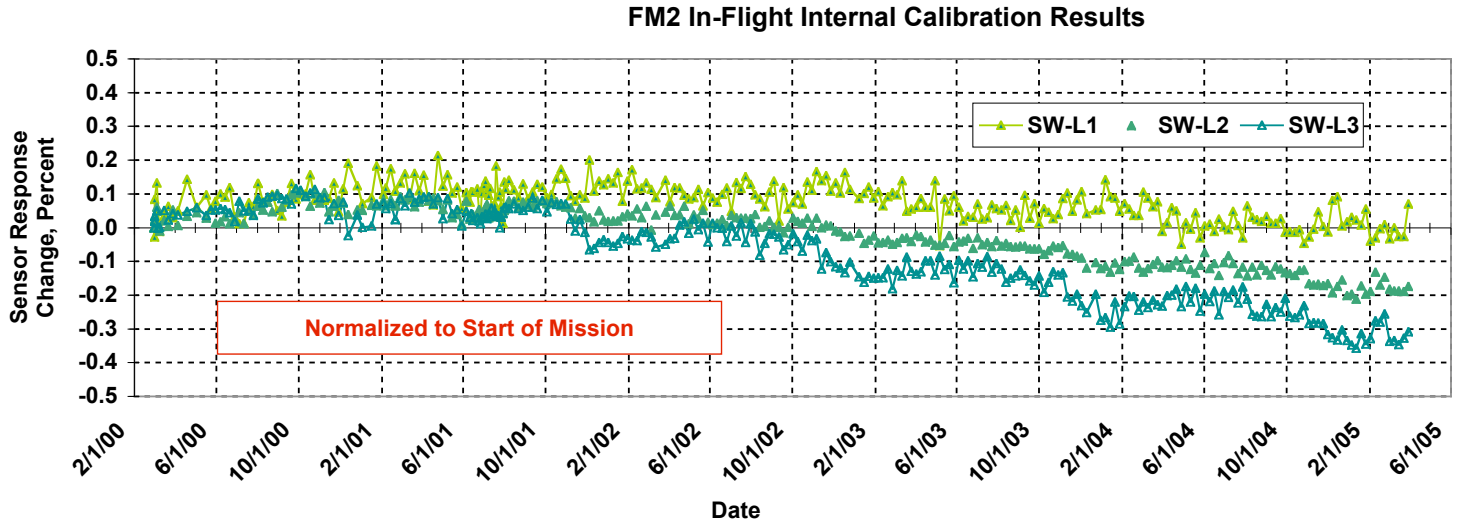




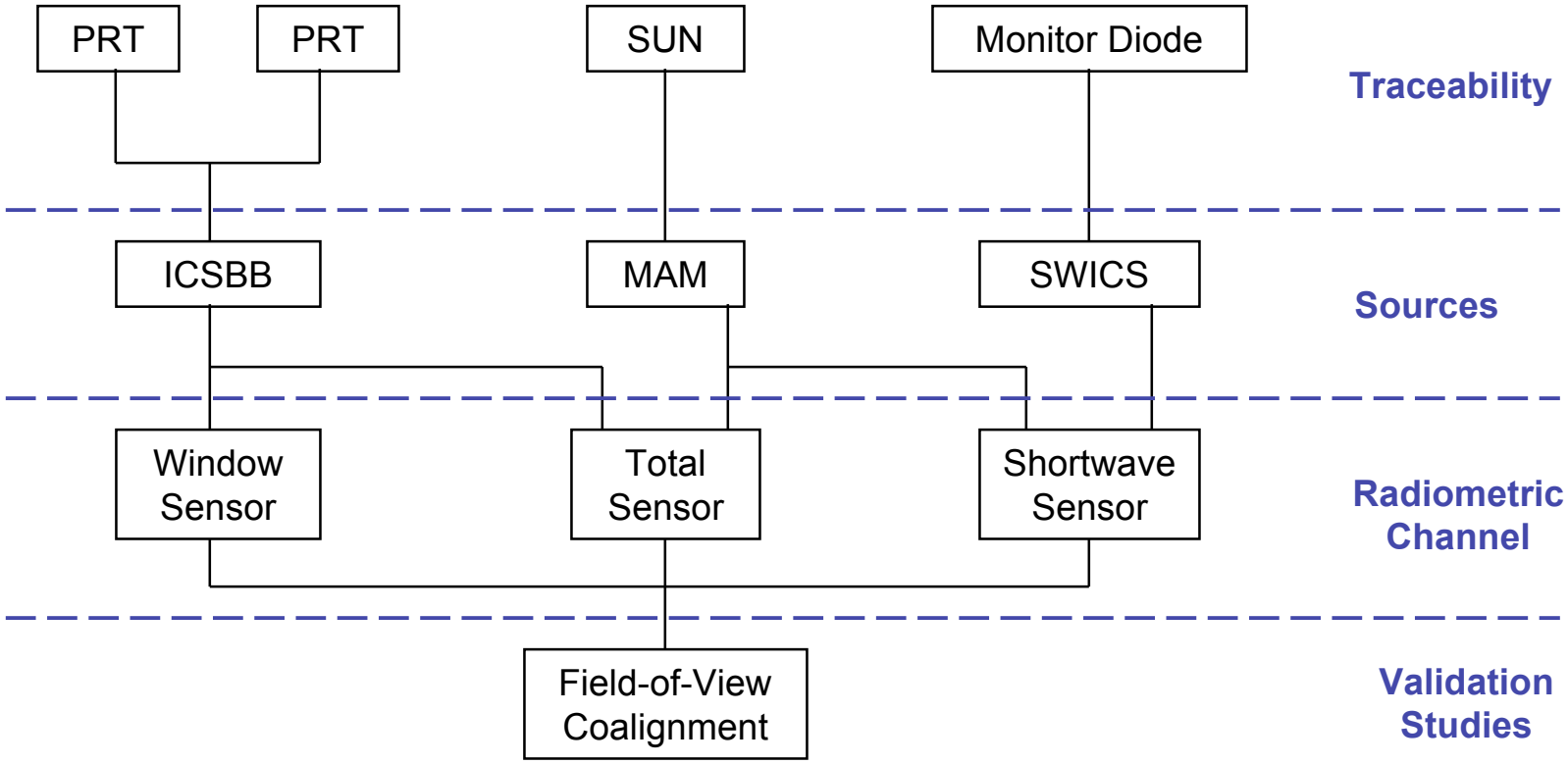


Terra SW Internal Calibration Results

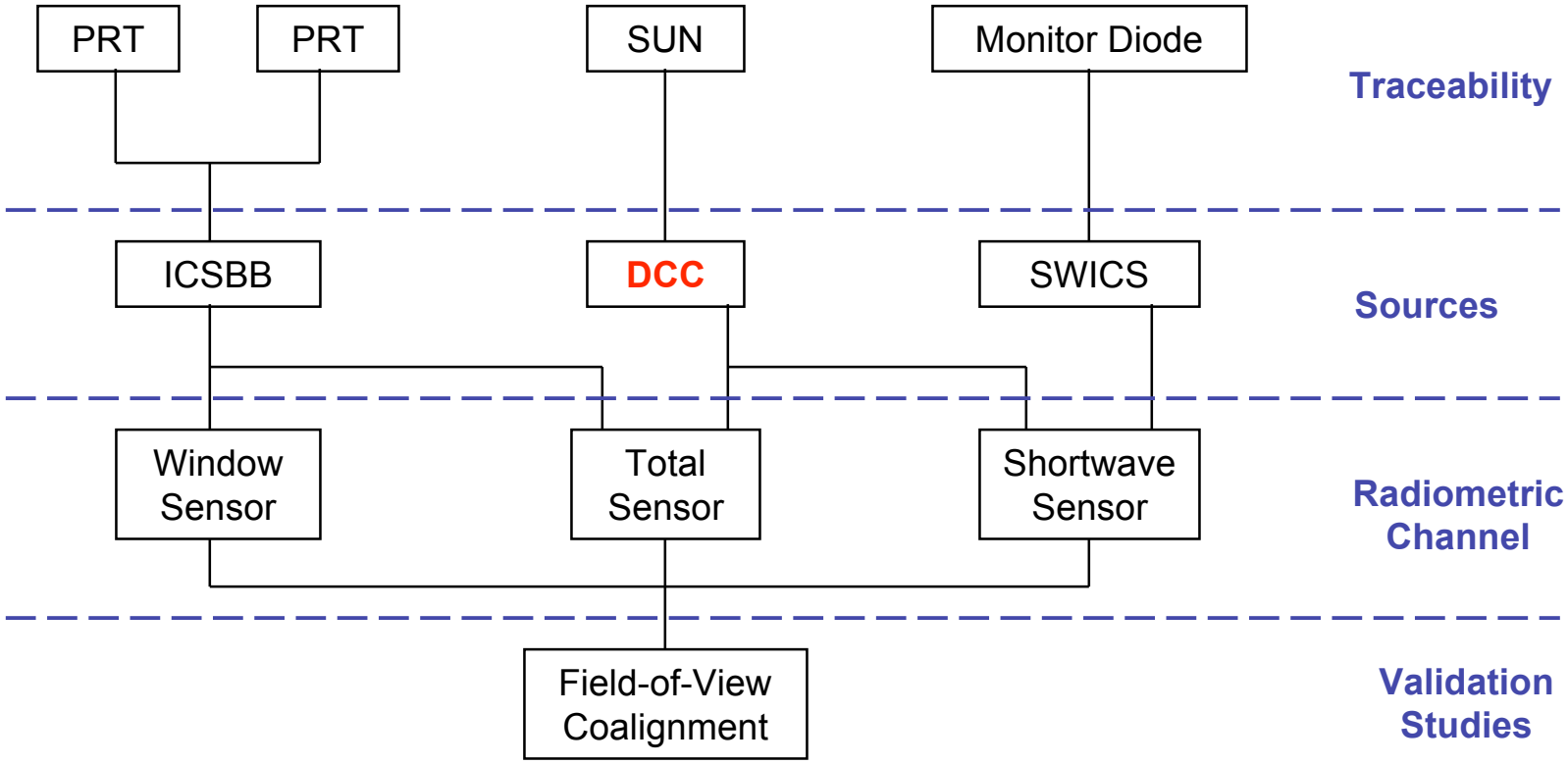




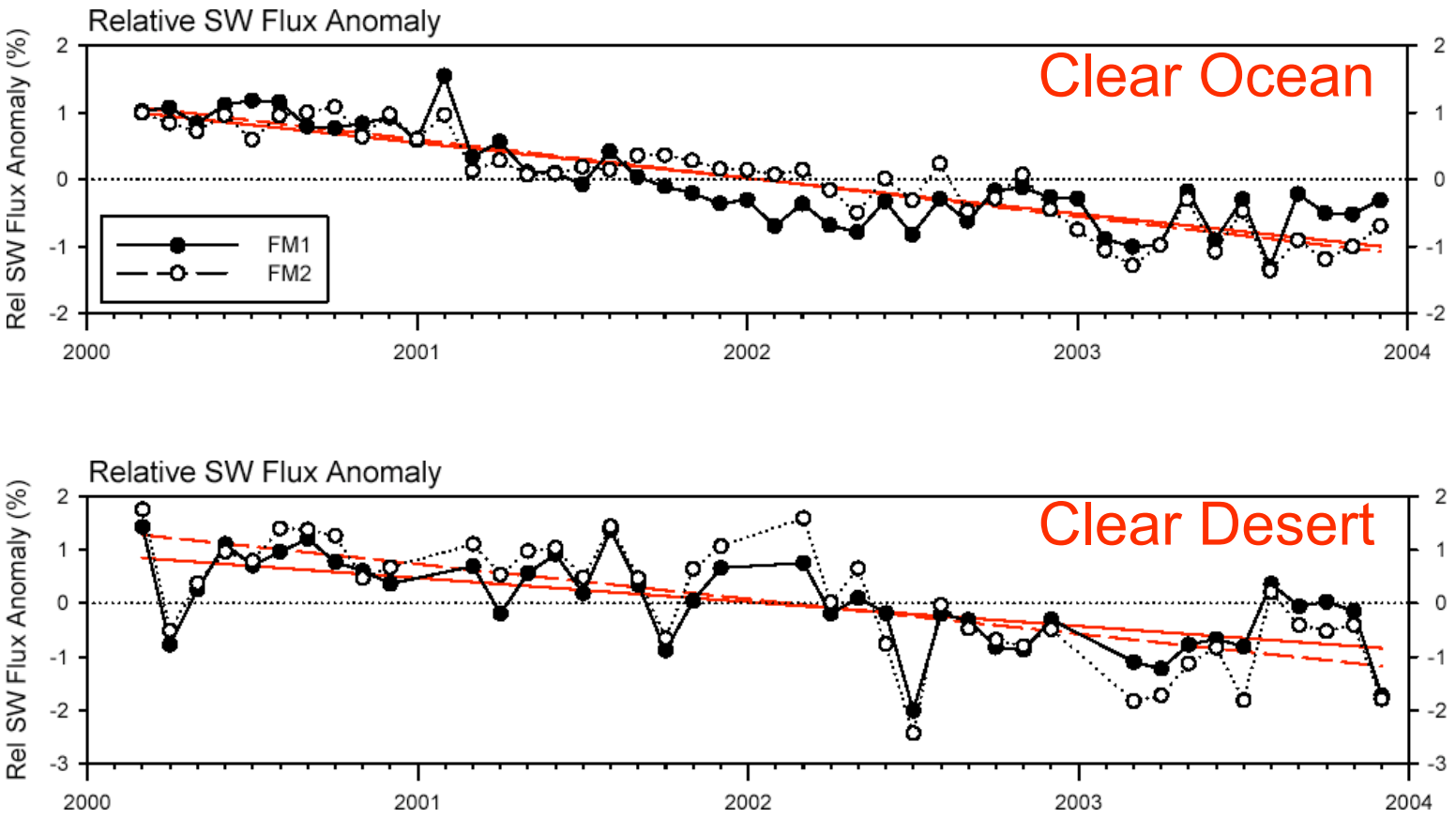
CERES Onboard Calibration Philosophy



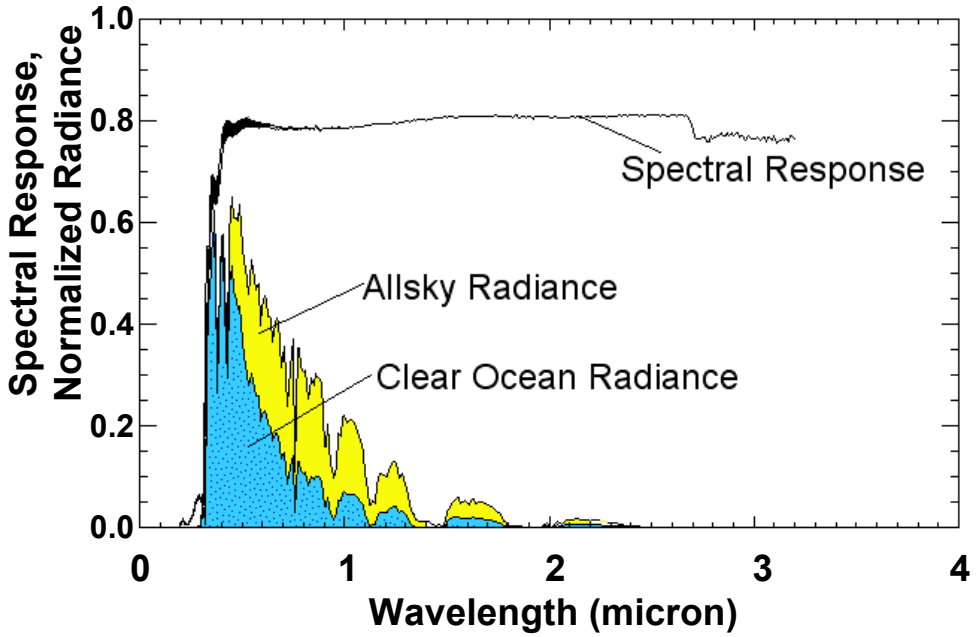
CERES Onboard Calibration Philosophy

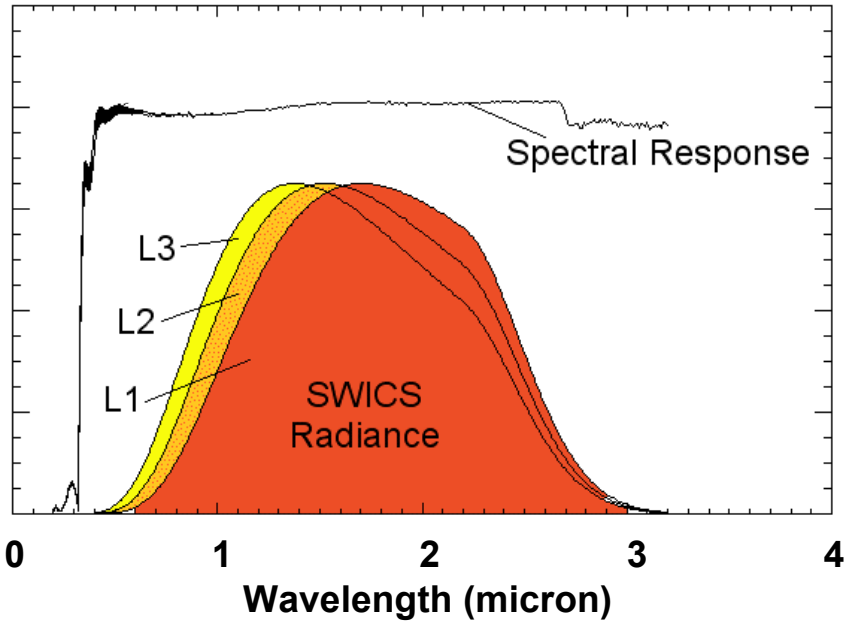


CERES SSF Ed2B SW TOA Flux Anomaly



Spectral Degradation : SWICS vs. Earth Spectra

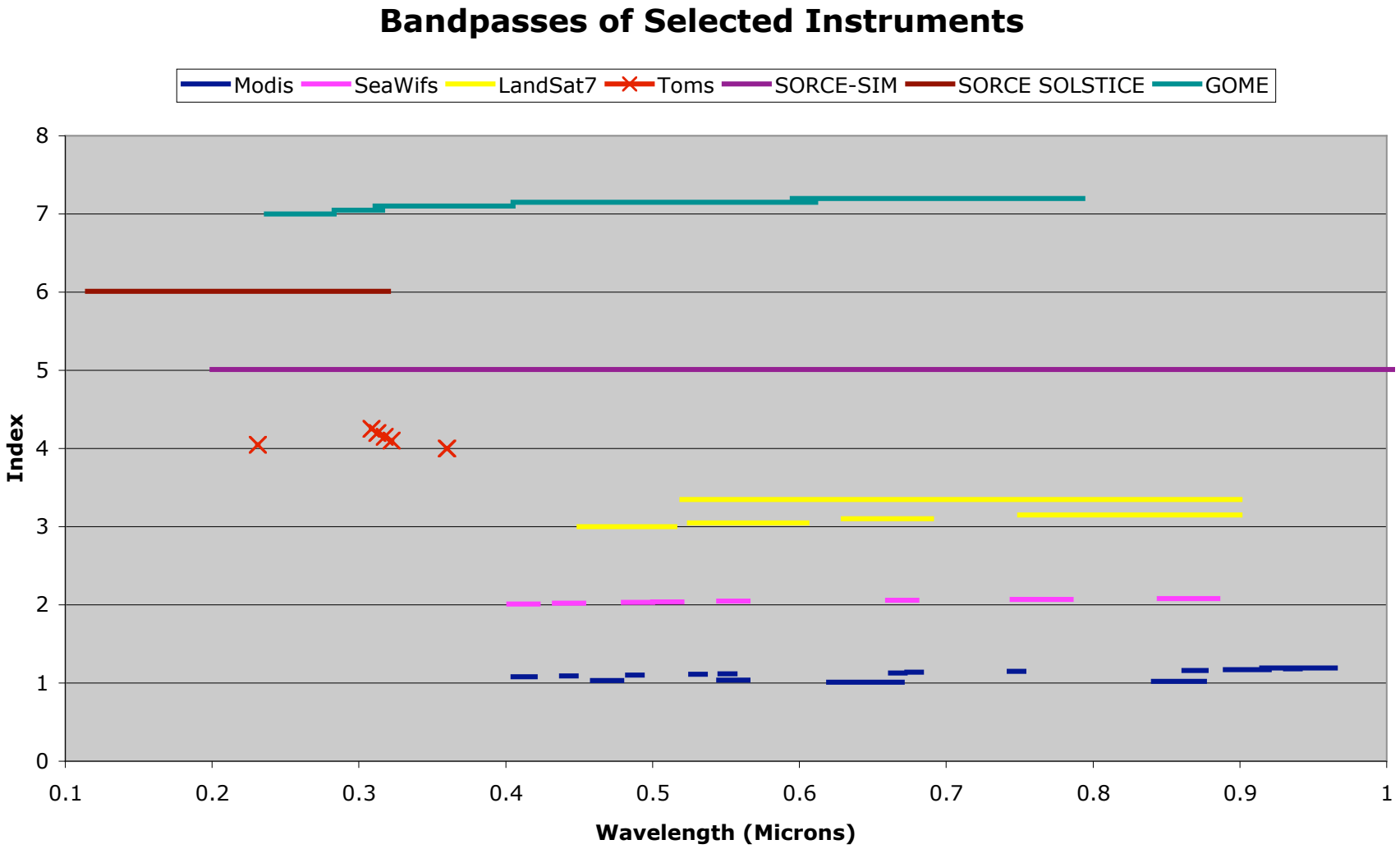




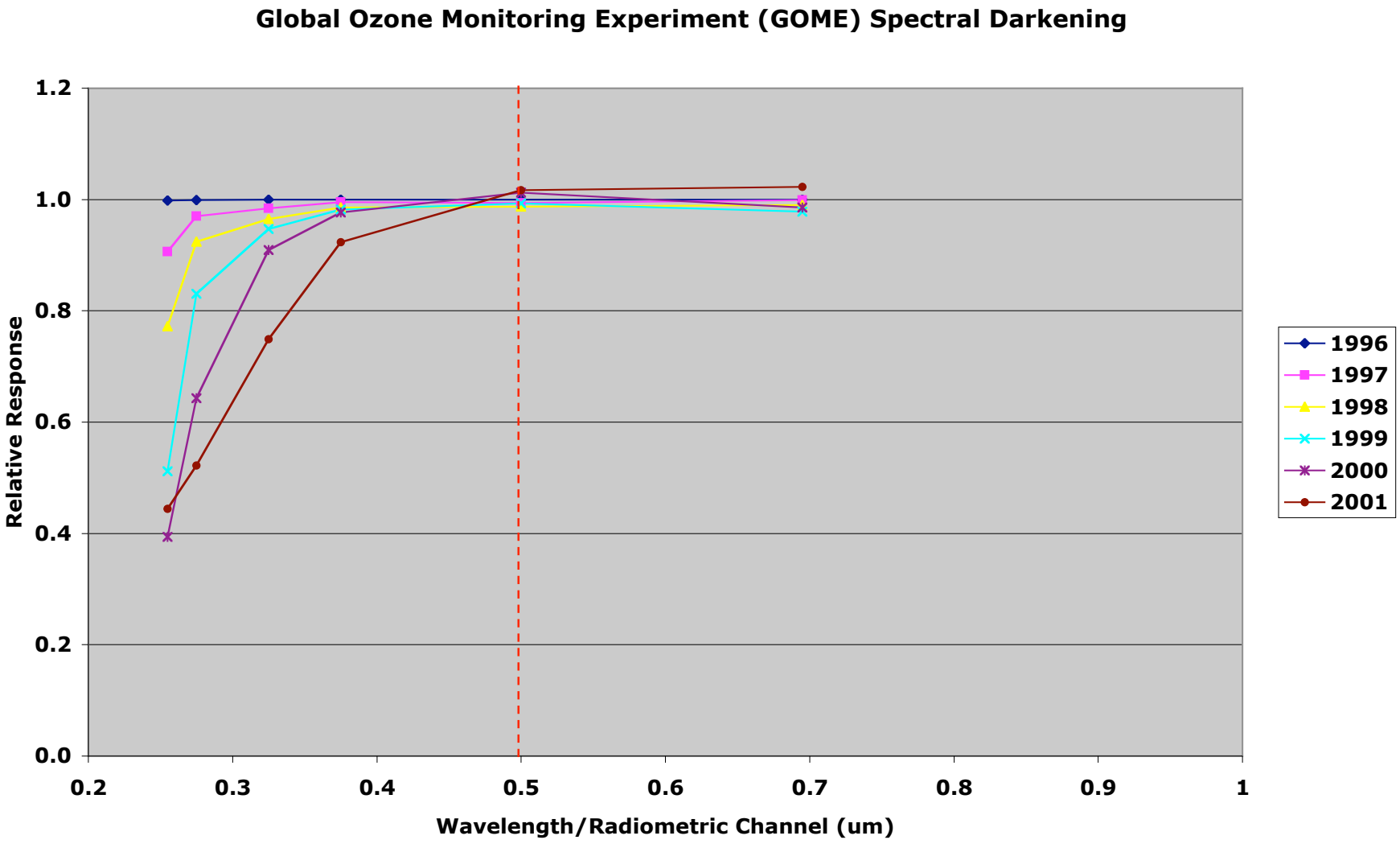
$$f^{sw}_{allsky} \text{ change} \approx -2\%$$

$$f^{sw}_{swics} \text{ change} \approx -0.1\%$$

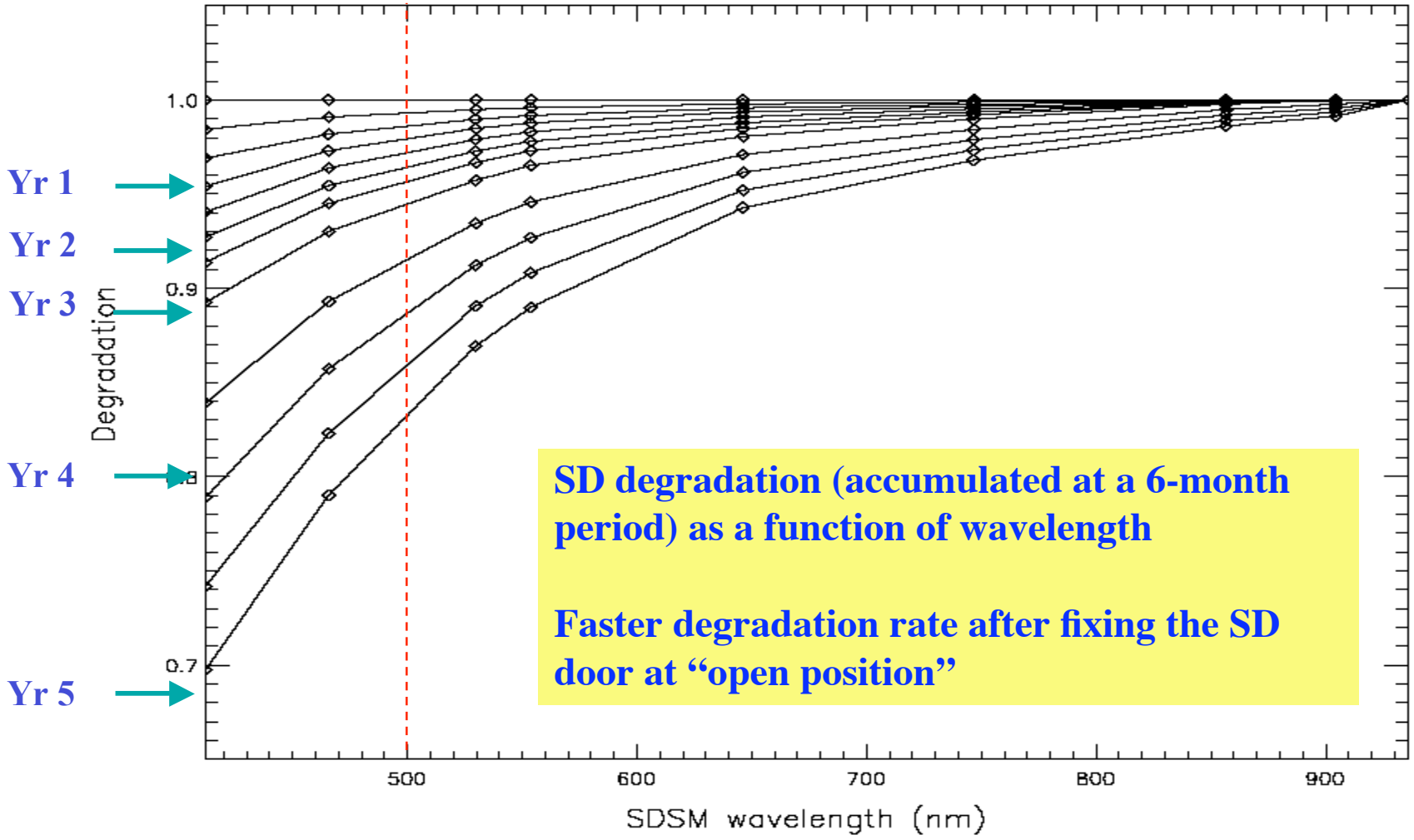
LEO Missions Subject to Spectral Darkening



Spectral Darkening on Similar Missions



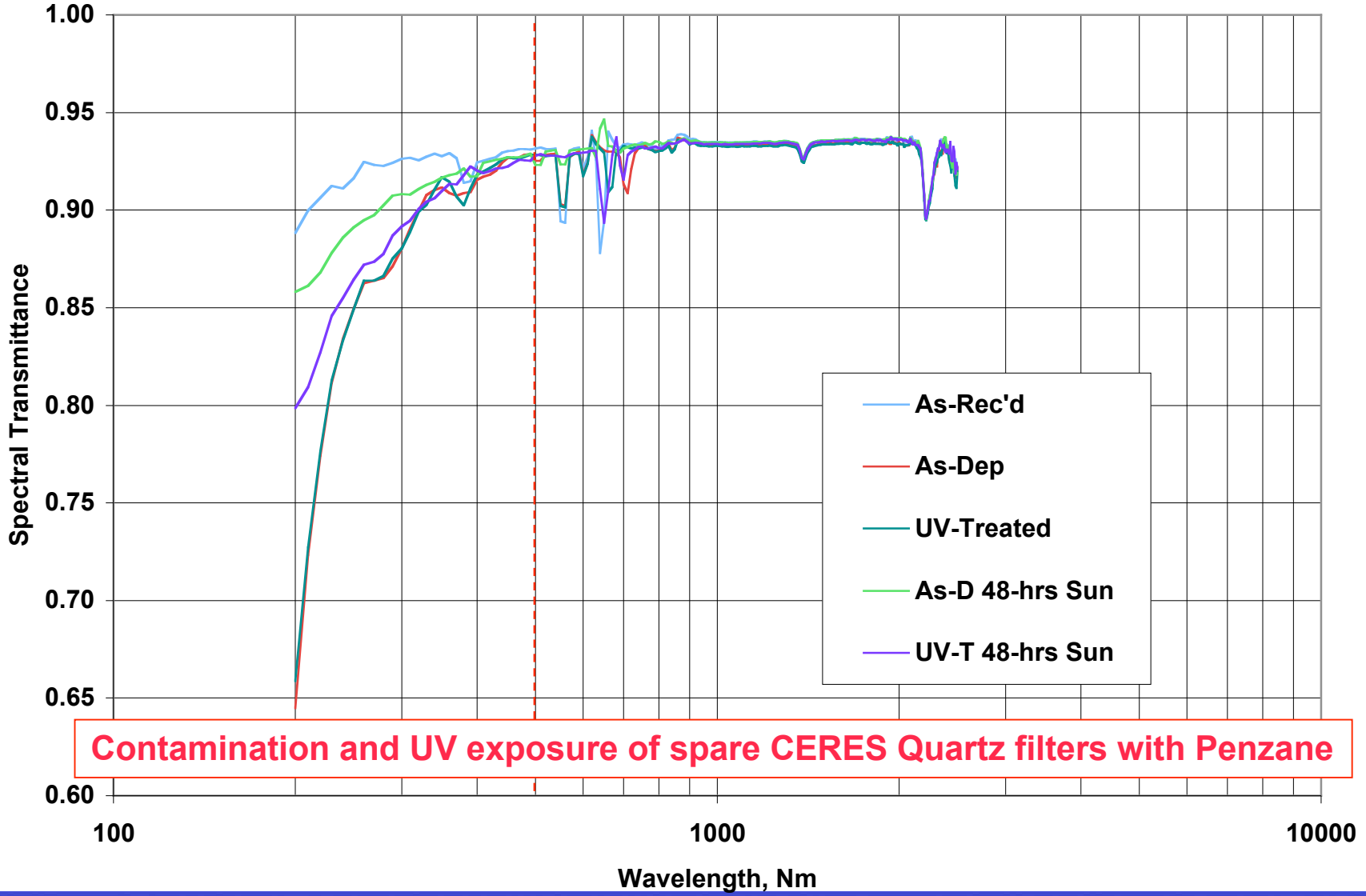
Modis Solar Diffuser Spectral Degradation



SD degradation (accumulated at a 6-month period) as a function of wavelength

Faster degradation rate after fixing the SD door at "open position"

Preliminary Results of Contamination Study



Contamination and UV exposure of spare CERES Quartz filters with Penzane

Direct Comparison of Nadir Radiance Measurements

Two CERES instruments on a common platform allows for a unique validation opportunity…..

Direct Comparison of simultaneous Nadir measurements

Each CERES/Terra instrument views nadir every 3.3 seconds

Thus, we obtain nearly simultaneous measurements of the same geo-location ($\Delta t < 3.3$ seconds)….

Spatial, angular, and temporal sampling issues are virtually eliminated.

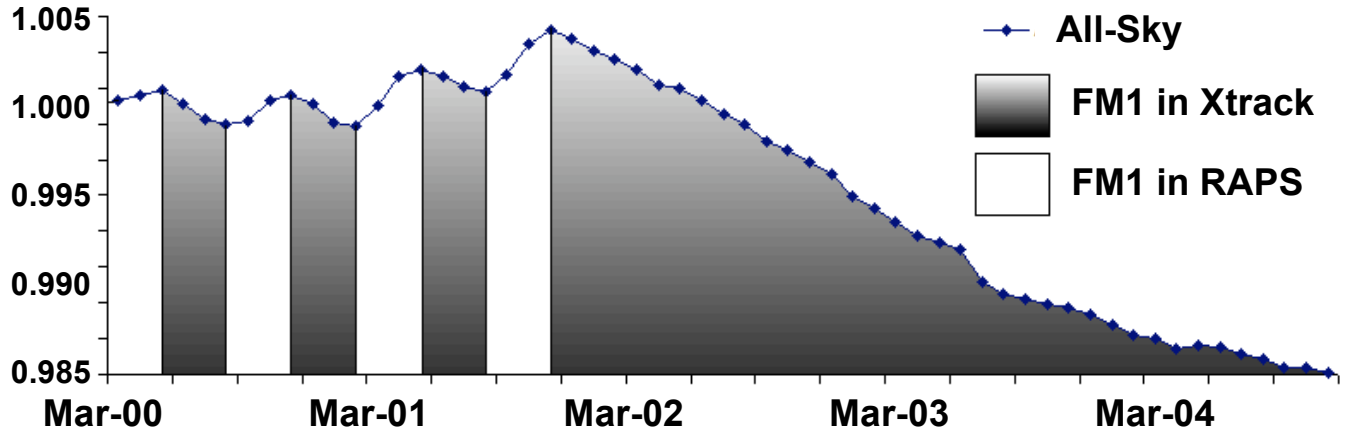
26,000 co-located (but not independent) measurements in a given day, provides a very rigorous statistical tool.

Results can be discretized by scene type to enhance the analysis.

Terra Edition2 Nadir Direct Comparison

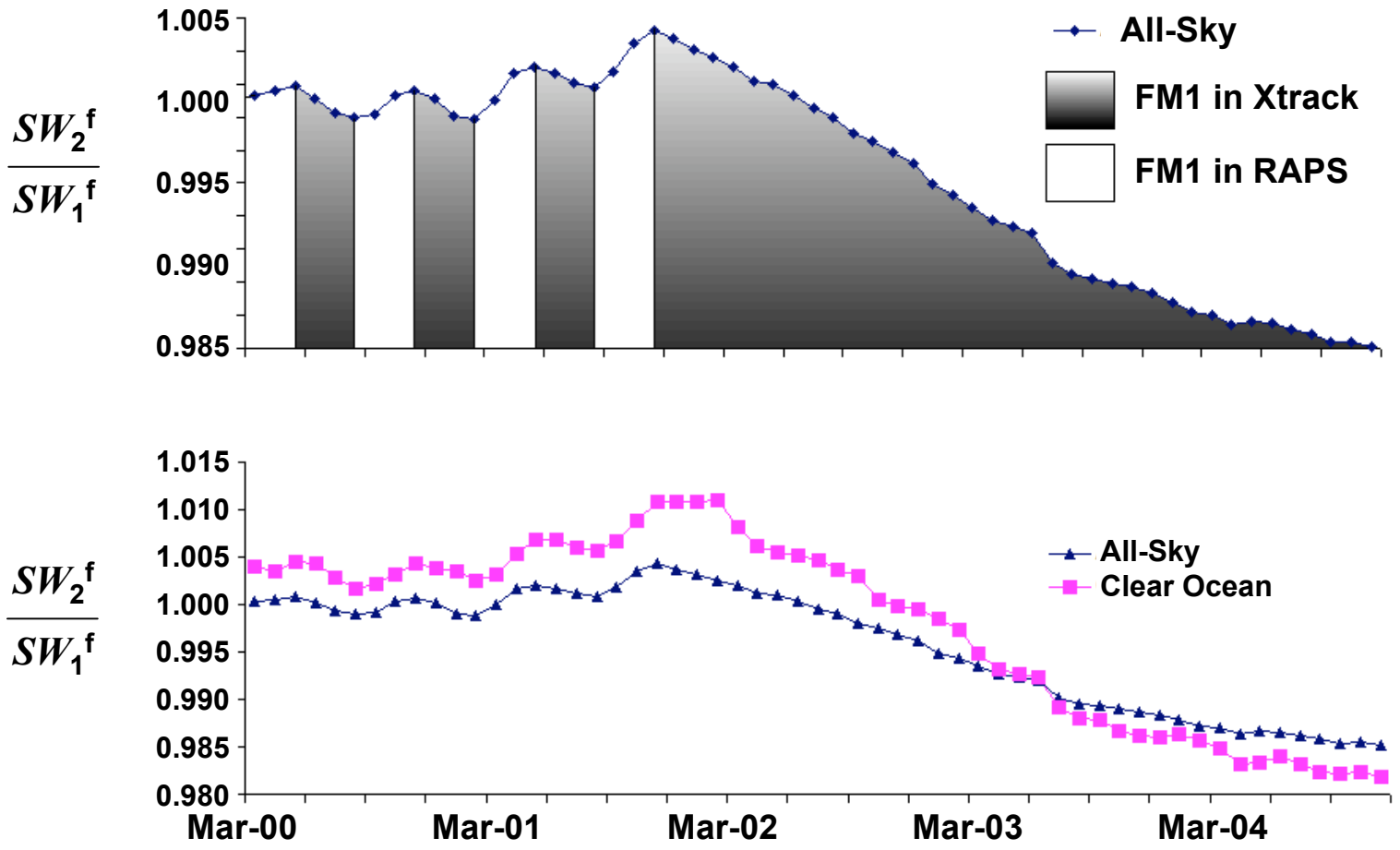
SW Nadir Radiances

$$\frac{SW_2^f}{SW_1^f}$$

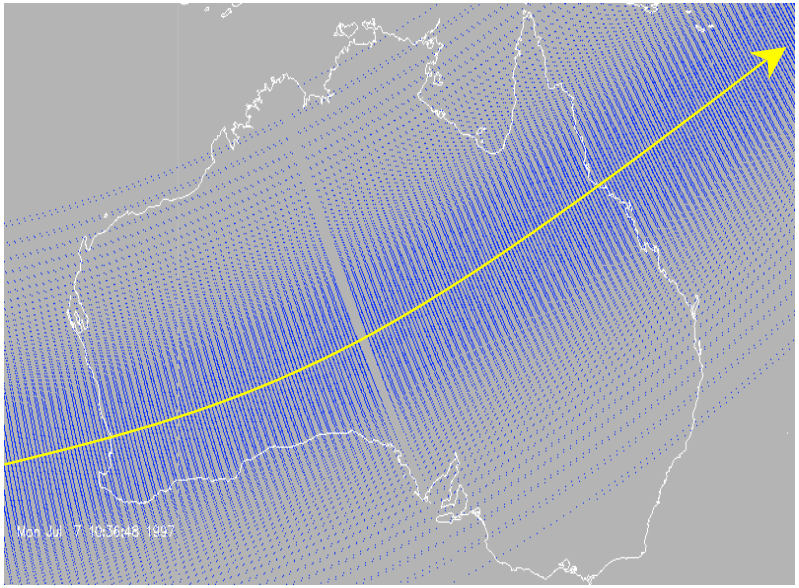


Terra Edition2 Nadir Direct Comparison

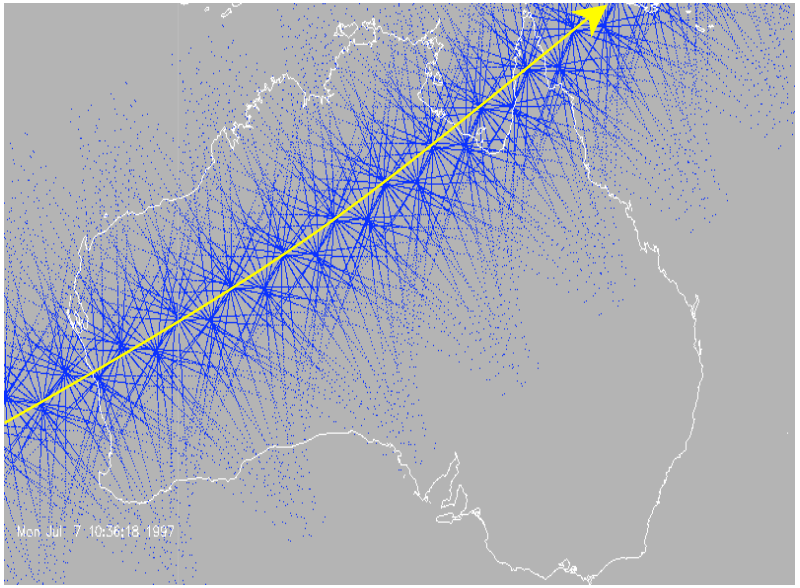
SW Nadir Radiances



Primary CERES Operational Modes

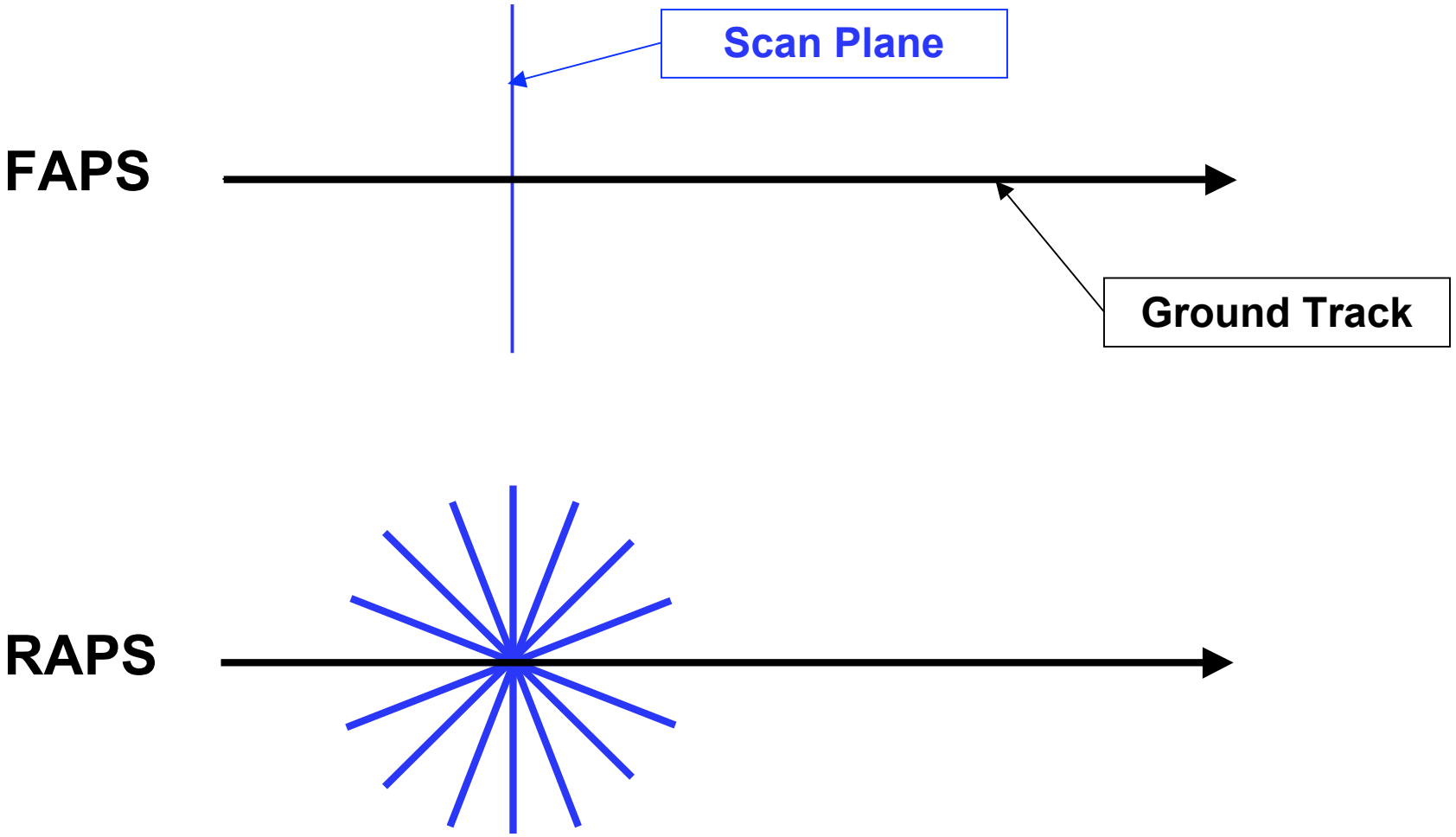


Fixed Azimuth Plane Scanning (FAPS, Xtrack)

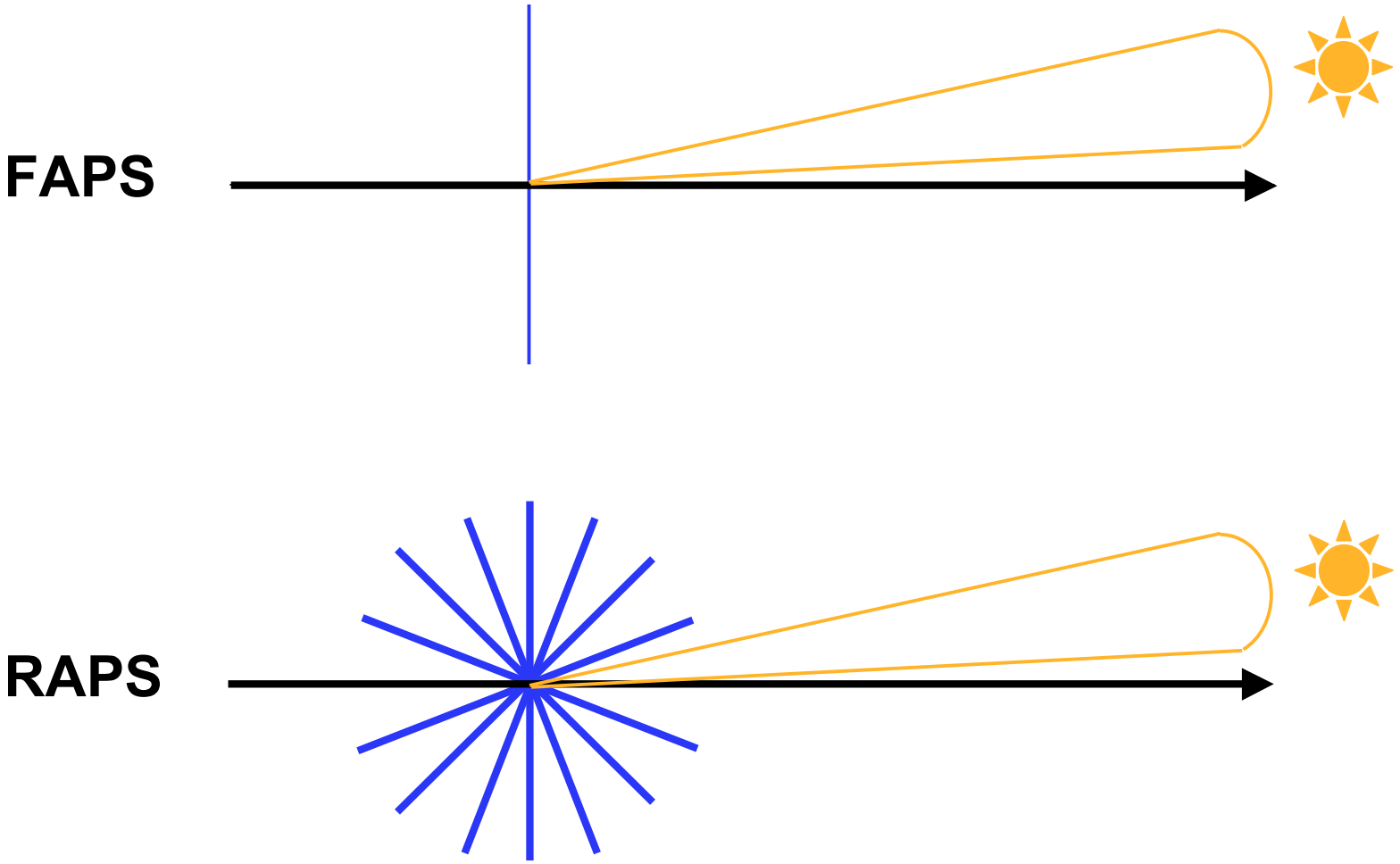


Rotating Azimuth Plane Scanning (RAPS)

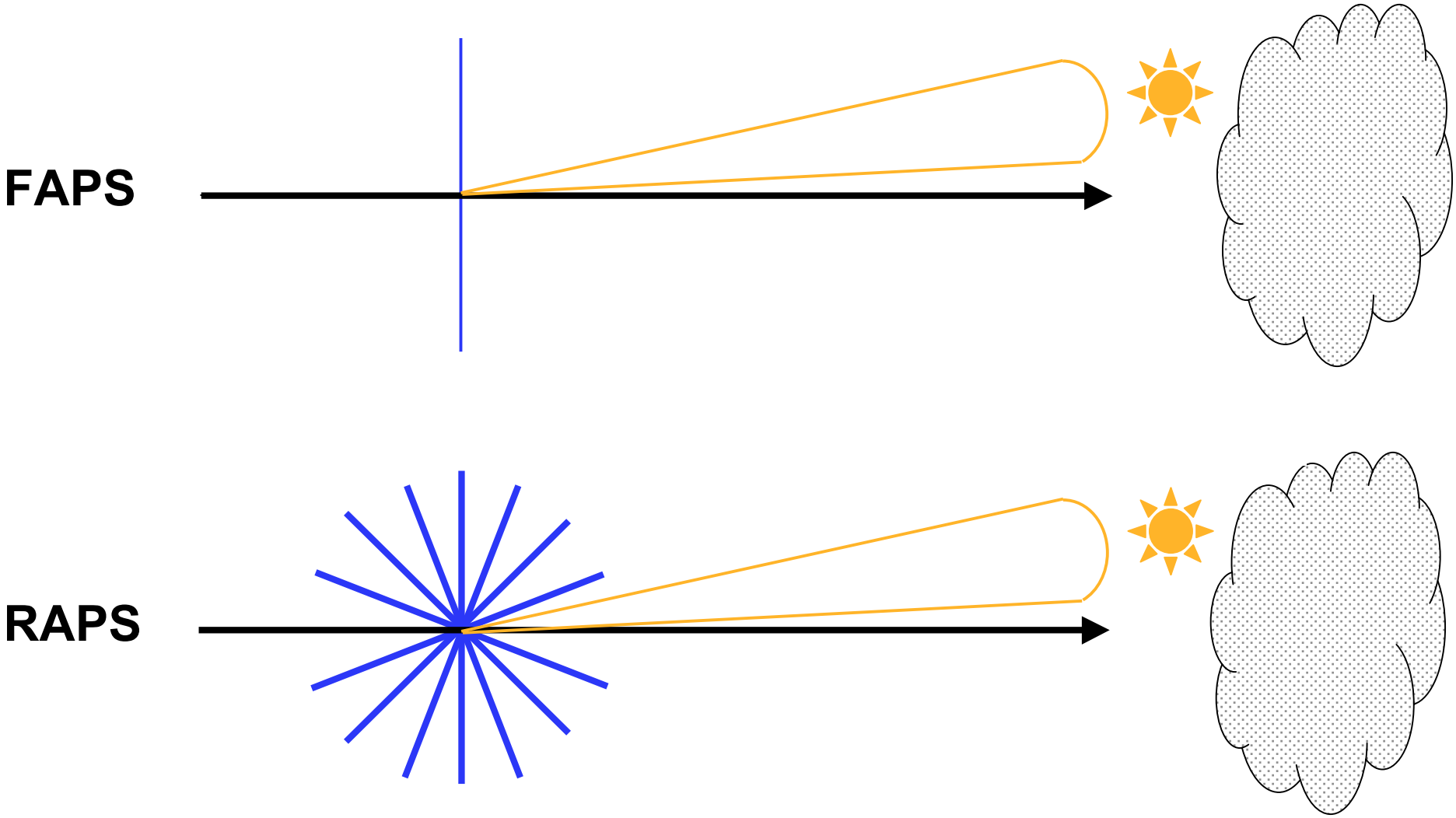
Whats the difference between RAPS and FAPS?



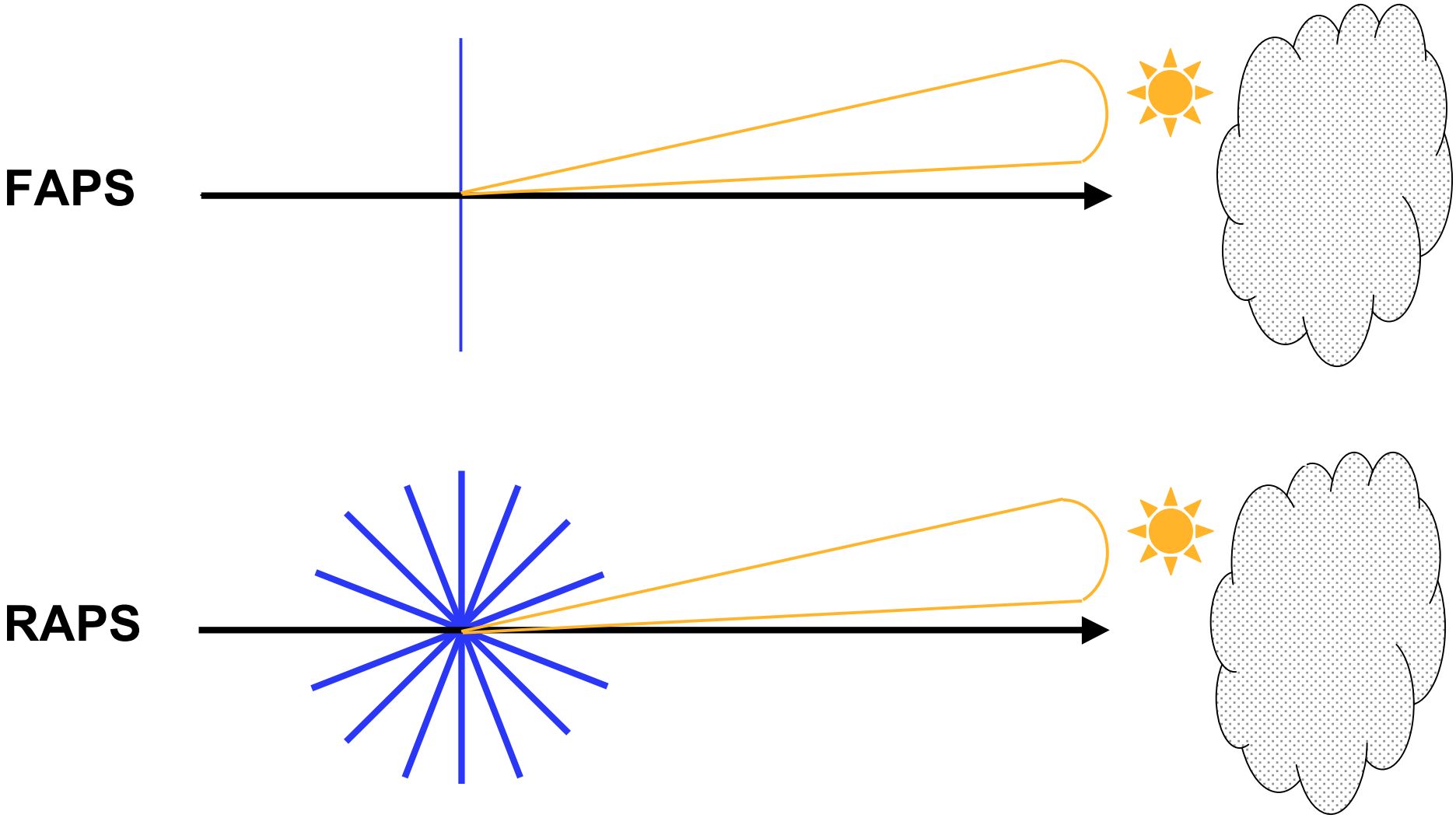
Whats the difference between RAPS and FAPS?



Whats the difference between RAPS and FAPS?



Whats the difference between RAPS and FAPS?



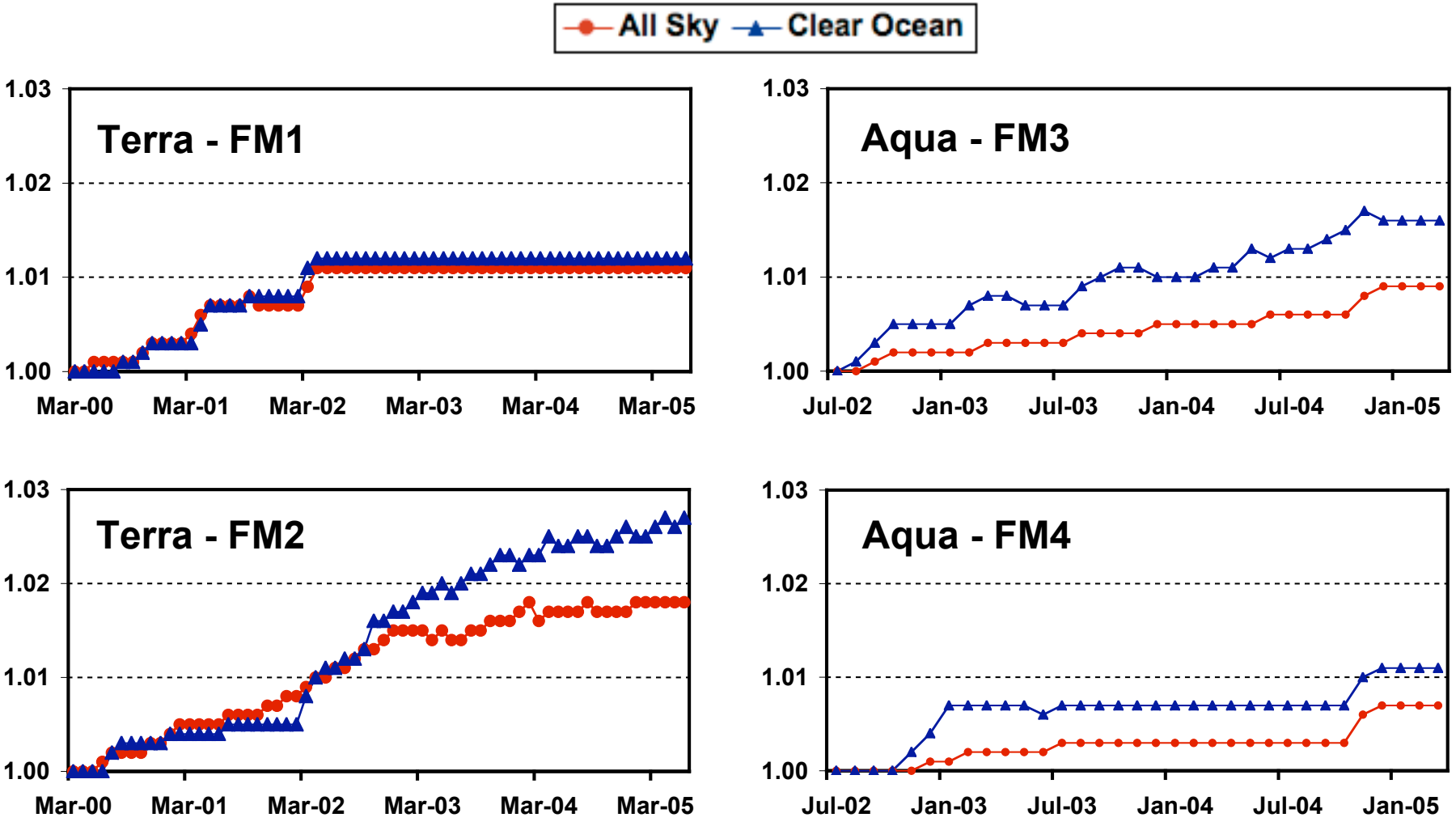
Edition2_Rev1 Scaling Factor Assumptions

Based upon this understanding, Rev1 scaling factors for SW fluxes were derived.

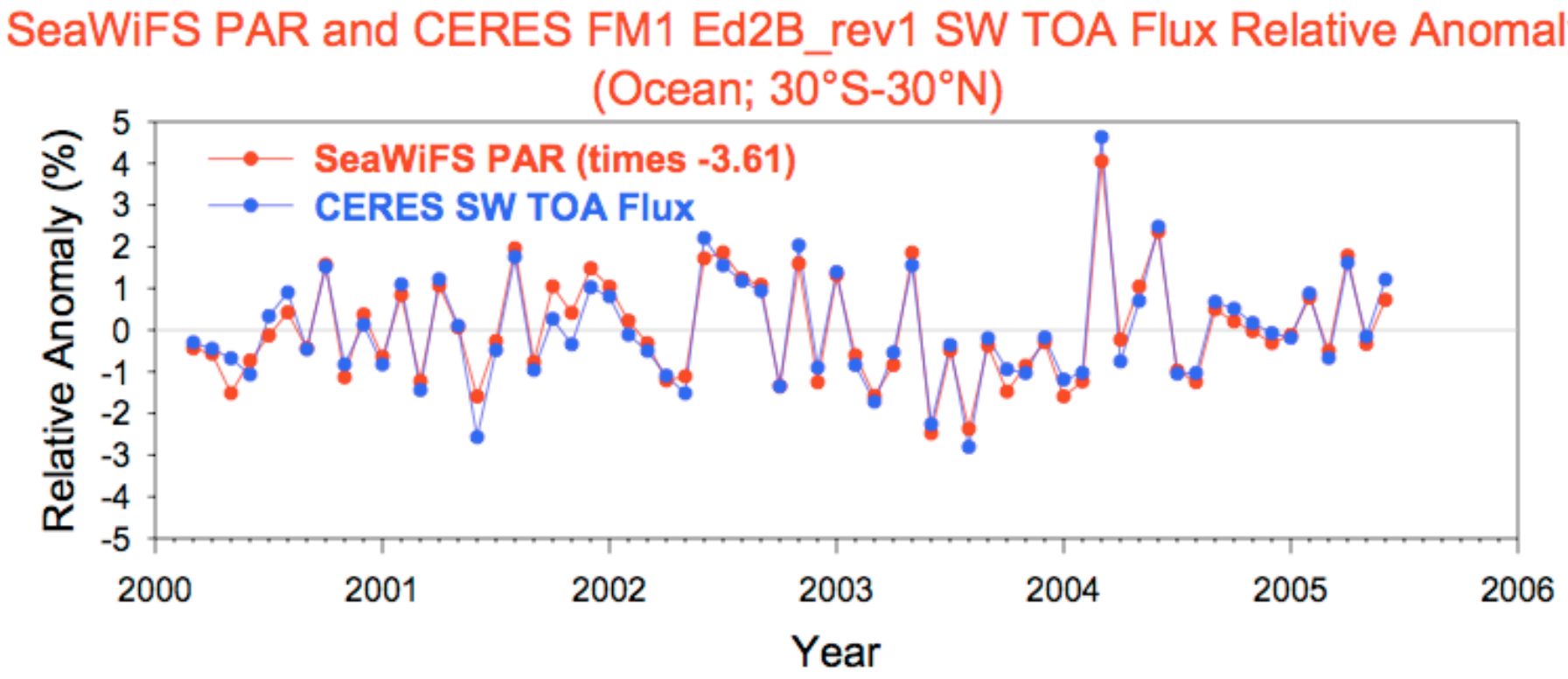
Explicit assumptions in developing Rev1 factors are:

- **RAPS instrument does degrades spectrally**
- **Xtrack instrument does NOT degrade spectrally**
- **Output of on-board lamps, SWICS, is perfectly stable.**

Edition2_Rev1 Scaling Factors



Application of Edition2_Rev1 Scaling Factors



Instrument Operations to Support Characterization

Is there evidence of active spectral darkening in crosstrack mode?

Test Platform: Terra

Operational Design: Stow one instrument while operating 2nd in Crosstrack mode.

Month	FM1	FM2
1,2	Xtrack	Xtrack
3,4	Xtrack	Stow
5,6	Xtrack	Xtrack
7,8	Stow	Xtrack
9,10	Xtrack	Xtrack

Metric: Compare matched footprints before and after stow period and test means for signifigance.

Operations to Characterize Spectral Darkening

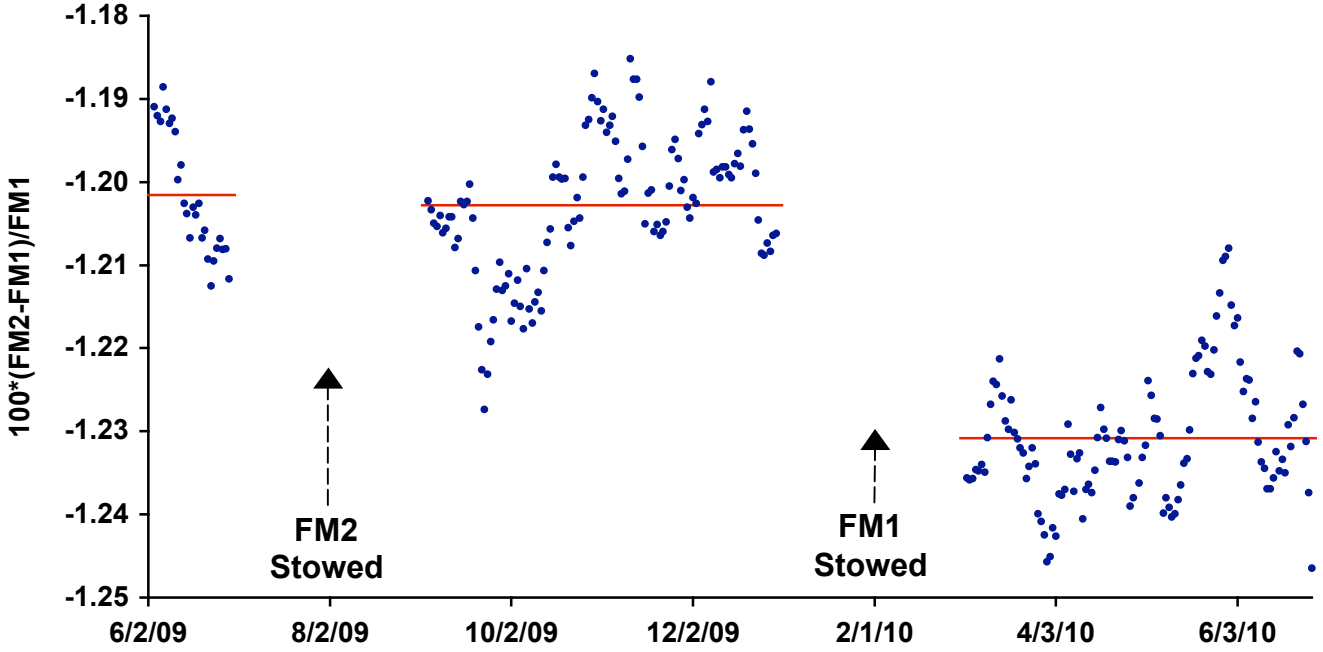
Year	Month	FM1 Azimuth Gimbal	FM1 Solar Calibrations	FM2 Azimuth Gimbal	FM2 Solar Calibrations	Direct Solar Exposure	RAM Direction	Darkening Rate Impact
2005	February 2005	Xtrack	Yes	Xtrack, Atrack	Yes	Nominal	Nominal[7]	Nominal
	March	Xtrack	Yes	Xtrack	Daily	Accelerated (FM2)	Accelerated(FM2)[8]	No Change
	April	Xtrack	Yes	Rotating	Yes	Reduced[1]	Nominal	No Change
	May	Xtrack	Yes	Rotating, Atrack	Yes	Eliminated[2]	Reduced[2]	
	June	Xtrack[3]	Yes	Xtrack[4]	No	Eliminated	Eliminated	
	July	Xtrack[3,5]	Yes	Stowed	No	Eliminated	Eliminated	
	August	Xtrack	Yes	Stowed	No	Eliminated	Eliminated	
	September	Xtrack	Yes	Xtrack[6]	No	Eliminated	Eliminated	
	October	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	November	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	December	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
2006	January 2006	Stowed	No	Xtrack	No	Eliminated	Eliminated	
	February	Stowed	No	Xtrack	No	Eliminated	Eliminated	
	March	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	April	Xtrack	No	Xtrack	No	Eliminated	Eliminated	
	May	Xtrack	Yes[9]	Xtrack	Yes[9]	Eliminated	Eliminated	
	June	Xtrack	Yes[9]	Xtrack	Yes[9]	Eliminated	Eliminated	
	July	Xtrack	Yes[9]	Xtrack	Yes[9]	Eliminated	Eliminated	
	August	Xtrack	Yes[9]	Xtrack	Yes[9]	Eliminated	Eliminated	
	September	Xtrack	Yes[9]	Xtrack	Yes[9]	Eliminated	Eliminated	

Notes:

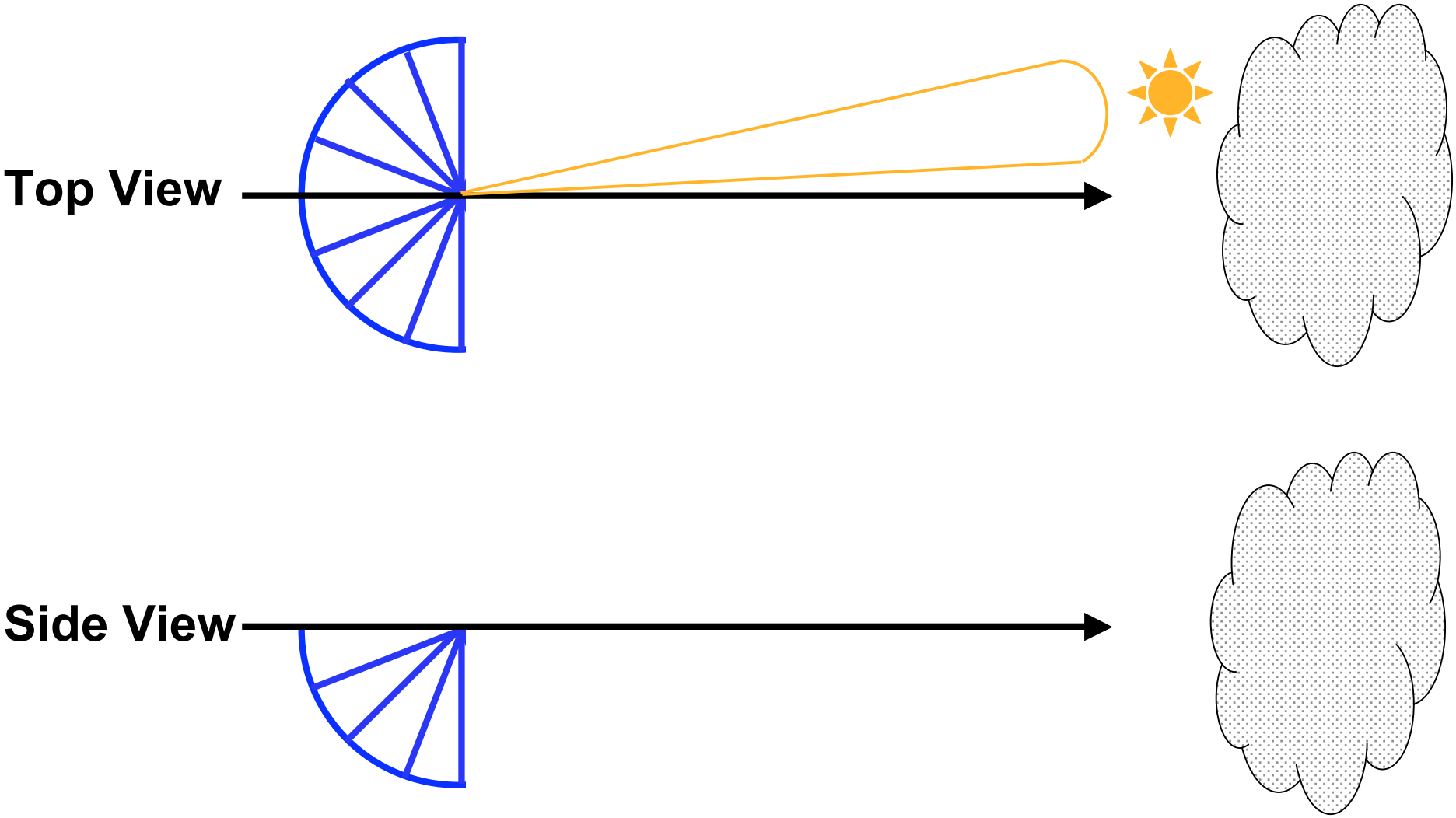
1. Short-Earth scan profile turn-around reduced 8^0, March 31, 2005 on FM1 and FM2.
2. Expanded solar-avoidance region criteria May 13, 2005.
3. Greenland Summer Solstice Terra-Aqua Inter-Calibration, June 6- July 6, 2005
4. GERB Operations, June 9-30, 2005.
5. Nighttime internal calibrations, July 1-7, 2000.
6. Valencia Over-Flights, September 12-17, 2005.
7. Lunar Scans
8. Solar Calibrations
9. Raster Scan A_Only Azimuth Sync Profiles

Terra Edition1_CV SW Full Swath Direct Comparison

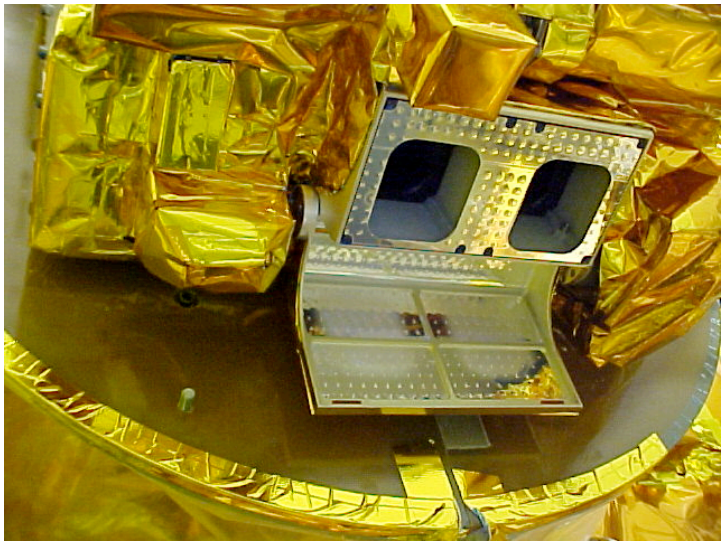
Is there evidence of active spectral darkening in crosstrack mode?

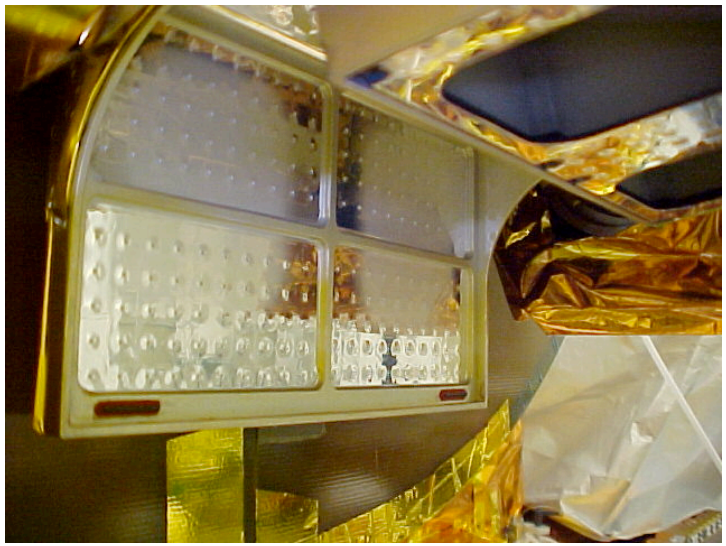


Visualization of new operational constraints



Foggy MAM Contamination Cover



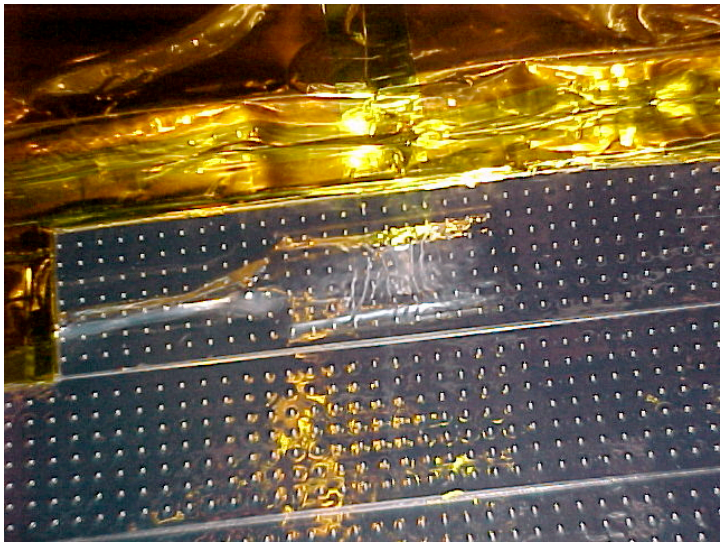


- Subsequent to spacecraft level thermal vacuum testing, a visual inspection of the FM-3 instrument revealed a ‘fog’ on the interior surface of the FM-3 MAM contamination cover.

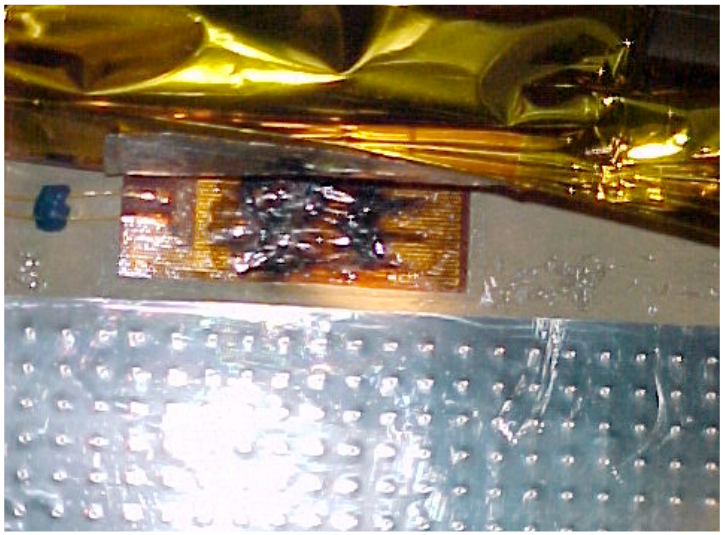
- Visual inspection of optics revealed no visible deposition.

- Testing yielded conflicting opinions of the material, most likely candidate was penzane lubricant.

Burnt CERES Aqua Test Heaters



Prior to spacecraft level thermal vacuum testing, spacecraft personnel overloaded test-only heaters on the CERES Aqua instruments.



Heaters were visibly charred and destroyed. Location is external to optical chamber and under silver teflon radiators. Heaters were removed and area cleaned prior to thermal vac testing.